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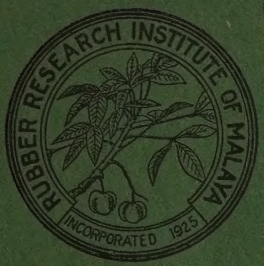

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IMPORTANT NOTE

This is the first Journal Communication to be published since the Institute resumed activities on liberation from Japanese Occupation in September 1945, and it appears as *Volume 12, No. 262.*

The last Journal Communication actually issued was *Vol. 11, Communication 259. Patent Specifications: Improvements in and relating to the Preparation of Softened Rubber.*

Two further Communications were prepared for publication in 1941 and were in proof form at the time of the Japanese invasion.

These communications were briefly reviewed on the back cover of the R.R.I. Planters' Bulletin No. 18 published in November 1941 but *were not issued in complete form.*

Vol. 11, Communication 260. Experiments with Economic Tapping Systems (2) Alternate-daily Periodic Tapping of Mature Seedling Rubber, Parts I and II by R. Scott Russell and Evan Guest.

This paper dealt with the results during the first two years of a series of tapping experiments on mature trees. With the proofs summaries of results for the third year of the experiments were recovered. Results for the third year showed that considerable alterations in the original draft would have been necessary. Since both investigators had left the staff of the Institute and as it was not possible to clarify the position by continuation of the experiments it was decided to withhold publication.

As the main conclusions quoted in the abstract are substantially correct, and reference to the publication has been made in other work, the Communication has been retained as No. 260 in the abstract form as published in Planters' Bulletin No. 18 November, 1941.

Vol. 11, Communication 261. The Packing of Sheet Rubber in Bales by J. H. Piddlesden.

Proofs of this Communication were lost so that it appears only in abstract form in Planters' Bulletin No. 18 November 1941. Because reference to it has been made in other publications the number is retained in the Communication Series to avoid confusion in future.

RETENTION OF PHOSPHATES BY MALAYAN SOILS

I. THE NATURE OF PHOSPHATE RETENTION IN DIFFERENT SOIL TYPES

BY

G. OWEN

It has long been known that most tropical soils have a high capacity for immobilising the phosphate applied as a fertiliser. The problem of phosphate retention in soils has received much attention in recent years but most of this work has been confined to soils of temperate regions. Apart from the work done on Hawaiian soils there is very little published work on the study of phosphate retention in lateritic red earths.

Malayan soils generally may be broadly classified as red and yellow soils of the lateritic type, and grey clay of alluvial origin. A marked deficiency of phosphate is a characteristic feature of these soils, the readily soluble or " available " fraction seldom exceeding 10 parts per million. Moreover these soils absorb large amounts of phosphorus when shaken up with aqueous solutions of a phosphate, and when the phosphate is applied as a fertiliser, the loss of this plant nutrient in drainage waters is extremely small. Yet it has often been observed that little response, when measured in terms of growth of rubber trees or yield of latex, is obtained when phosphatic fertilisers are applied to some of the local soils. The reason for this is that easily soluble phosphate, when added to soils, is changed into forms which are much less soluble. This is known as " phosphate fixation."

The conversion by soils of readily soluble forms of phosphate into relatively insoluble forms has very important consequences. A large proportion of the phosphate added to local soils is immobilized and its availability to plants is often so low that response to treatment is either not apparent or is extremely small. Even in soils of temperate regions it is maintained that only about 20 per cent. of the phosphate added is recovered in the crops, but in Malayan soils, in view of the greater degree of fixation, the amount recovered may be appreciably less.

It is clear that in order to ensure the most economic and efficient utilization of phosphate fertilisers in local soils it is necessary that we should know something about the fate of the phosphate after it is applied and the various reactions

which take place resulting in its adsorption, and ultimately its fixation in unavailable form. It was with this object in view that a long term investigation was carried out during the period immediately preceding the Malayan war, using as material, selected samples of the more important soil types of Malaya.

Meaning of Phosphate Retention

The term " retention " as used herein has reference to the removal of phosphorus from solution by the soil regardless of the manner or agency. The term used most frequently in the literature is " phosphate fixation " and sometimes " adsorption " but the writers differ to a great extent in the meaning which they attribute to these terms. The word " fixation " is sometimes used to mean loss of availability to plants, sometimes loss of solubility, and often retention against leaching. To avoid ambiguity the term " fixation " in this paper will be used to mean conversion of soluble forms of phosphate into difficultly soluble forms, while the term " retention " is given the definition stated above. Part of the phosphate retained or absorbed by the soil will be available to plants but the " fixed " phosphate is largely unavailable or difficultly available.

The retention of phosphate has been attributed by some to chemical reaction with soil bases. Phosphate in solution unites with soluble forms of iron, aluminimum and calcium to form relatively insoluble phosphate compounds. In neutral or calcareous soils insoluble phosphates of calcium are formed. Harrison and Das (8) found that mono-calcium phosphate combines rapidly with calcium carbonate to form di-calcium phosphate and that this in turn reacts more slowly to form the less soluble tri-calcium phosphate. Mc. George and Breazeale (15) state that the phosphates in the calcareous soils of Arizona exist in combination with larger amounts of calcium than exist in tri-calcic phosphate and suggest the following formulae as possibilities: 3 $Ca_3(PO_4)_2.Ca(OH)_2$ and 3 $Ca_3(PO_4)_2.CaCO_3$. They add that these high calcium phosphates are quite insoluble and unavailable to plants, and conclude that it is highly probable that calcium plays an important part in the fixation of phosphorus in unavailable forms in calcareous soils.

Retention and fixation of phosphate in acid soils is of more interest to us since Malayan soils invariably have a more or less strongly acid reaction. Evidence has been produced to show that in acid soils the immobilization of

phosphate is mainly due to the formation of iron and aluminimum phosphates. (13, 14). Ford (6, 7) studied retention and availability of applied phosphate, and found a tendency in certain soils toward a lack of response to treatment due to a change in the form of the applied phosphorus. His work indicates that certain iron and aluminium minerals in the soil are largely responsible for this change. Coleman (3) concludes that a considerable amount of the phosphorus fixed by clays, especially the large amounts fixed under the more acid conditions, is due to the replacement of hydroxide irons in the iron and aluminium compounds by the phosphate. Floyd Heck (6) is inclined towards the belief that retention of phosphate occurs largely through reactions with active calcium, iron or aluminimum, these elements being regarded as active when they unite chemically with phosphorus. Whether calcium, iron or aluminium phosphate is formed depends upon the reaction of the soil. Further, he regards the phosphorus retained in these forms as falling into three groups, (a) the readily available [$Ca_3(PO_4)_2$], (b) the moderately available [$AlPO_4$] and (c) the difficulty available forms [$Fe\ PO_4$, $Al_2(OH)_3\ PO_4$, $Fe_2(OH_3)PO_4$]. The same writer reports that in Hawaiian laterites retention was largely as the basic forms of iron and aluminium phosphates. Chandler (2) presents evidence to show that various agencies are active in causing retention of phosphate and that retention within the pH range of most acid soils was due primarily to the formation of insoluble iron and aluminium phosphates.

More recent investigators however are inclined towards the belief that the phenomenon of retention can largely be accounted for by absorption. It is known that the colloidal complex of soil plays a major role in retaining added phosphate. The explanation put forward is that absorption of phosphates by the soil colloids proceeds on the principle of anion exchange. Whether the phenomenon can be regarded as one of absorption or adsorption is not proven, but Davis (4) points out that there is possibly little or no true distinction between adsorption and absorption of phosphates by minerals and he feels that all the evidence supports the hypotheses of an absorption with some adsorption. Williams and Stewart (19) conclude that the results of their investigation are compatible with an adsorption of phosphate by soil colloids such as iron and aluminium hydrogels and clay minerals. Kurtz, De Turk and Bray (11) while recognising that a variety of reactions may occur, demonstrate that the

reaction between soluble phosphate and Illinois soils has many characteristics of adsorption.

Measurement of Phosphate Retention

A study of the literature reveals that various procedures are used by the different investigators; all are empirical and no one method has been generally or officially accepted. The writer selected two methods for comparison: (*1*) Floyd Heck's method (10) and (*2*) a procedure followed by Demolon and Barbier (5). Preliminary tests were carried out to ascertain the relative suitability of the two methods for determining the degree of retention of phosphate in Malayan soils. It was found that the method suggested by Demolon and Barbier gave more consistent results and was generally more suitable for routine determinations in the laboratory. This method was therefore adopted, details of which are as follows: 50 grams of air dried soil, which had passed through a 2mm sieve, were shaken for one half hour in an end over end shaking machine with 500 cc of 1% Acetic acid containing specified amounts of phosphate. Three determinations were carried out on each soil. (*1*) 50 grams soil + 500 cc. Acetic aid, (*2*) 50 grams soil + 500 cc. Acetic acid containing 25 miligrams P_2O_5 and (*3*) 50 grams soil + 500 cc. Acetic acid containing 50 milligrams P_2O_5. The phosphate was supplied as potassium dihydrogen phosphate. The suspension was filtered after shaking and the P_2O_5 content of the filtrate was determined by taking an aliquot ranging from 1 to 25 cc. depending on the P_2O_5 content of the solution, and the colour was developed immediately as in the Truog method (18). Colour comparisons were made using Spekker's Photoelectric Absorptiometer. The degree of retention of phosphate was calculated by difference between the amount added and the amount recovered in solution, and expressed as a percentage of the amount added.

Results of experiments showed that there was a slight increase of retention of phosphate with time of shaking. Retention also increased with increasing time of contact of soil with solution after shaking for one half hour. The sharpest rise however occurred during the first 24 hours, after which time the increase was more gradual (Table 1).

TABLE I

Soil	Mgms. P_2O_5 added to 50 grams soil	Percentage P_2O_5 retained after shaking (½ hr.) and allowing to stand for:—						
		0 hrs.	24 hrs.	41 hrs.	50 hrs.	65 hrs.	71 hrs.	95 hrs.
M.	25	82.8	91.1	91.1	92.2	91.2	90.8	93.4
R.	25	65.5	73.0	79.9	83.6	82.4	81.4	85.0
M.	50	73.4	84.5	84.7	89.0	84.7	85.9	88.5
R.	50	53.2	64.4	64.4	76.5	65.5	72.6	76.4

Any laboratory method is necessarily approximate and the object was to aim at a standardized procedure which will give consistent comparable values. It is concluded that the results obtained by shaking for one half hour and then allowing the soil to remain in contact with the solution overnight before filtering, gives a fairly reliable measure of the comparative abilities of the various soils to retain phosphates. This technique was adopted as standard routine for all subsequent determinations.

Retention of Phosphate by Different Soil Types

Profile samples of a variety of the better known soil types of Malaya were collected and the degree of retention of phosphate determined according to the method described.

The soils listed below are typical samples of well established soil types which cover relatively large areas in Malaya. All have a low base content and a more or less strongly acid reaction. Profile samples of soils A to G were obtained and the phosphate retention by the various horizons of these profiles is discussed in this section. Soils H, K, M, R and S are samples of the surface horizons of soil types similar to those included in the series A to G, which were used for further investigation on phosphate retention and discussed in other sections of this paper.

Soil	*Location.*	*Parent Material*
A	Bertam Estate, Province Wellesley ..	Alluvium (Coastal).
B	Bagan Datoh Estate, Perak	,, (,,).
C	Sungei Bekok Estate, North Johore ..	Granite.

Soil	*Location*	*Parent Material*
D	Riverview Estate, Perak ..	Sandstone (Weathered Quartzite).
E	Ulu Sawah Estate, Negri Sembilan ..	Altered shales of the Raub Series.
F	Rengo Malay Estate, North Johore ..	Quartz-mica Schists. (?)*
G	Jabor Valley Estate, East Pahang ..	Dolerite.
H	Huntly Estate, Perak ..	Alluvium (Coastal).
K	Buan Heng Estate, South Johore ..	Granite.
M	Effingham Estate, Selangor	Quartz-mica Schists. (?)*
R	Sungei Buloh, Selangor ..	Sandstone (Weathered Quartzite).
S	Semambu Estate, Pahang	Dolerite.

Mechanical analysis of samples from the various horizons of the profiles of soils A to G was carried out and the percentages of silica and sesquioxides in the clay fractions were determined. The results were studied in relation to the capacity of the various soils for retaining phosphate.

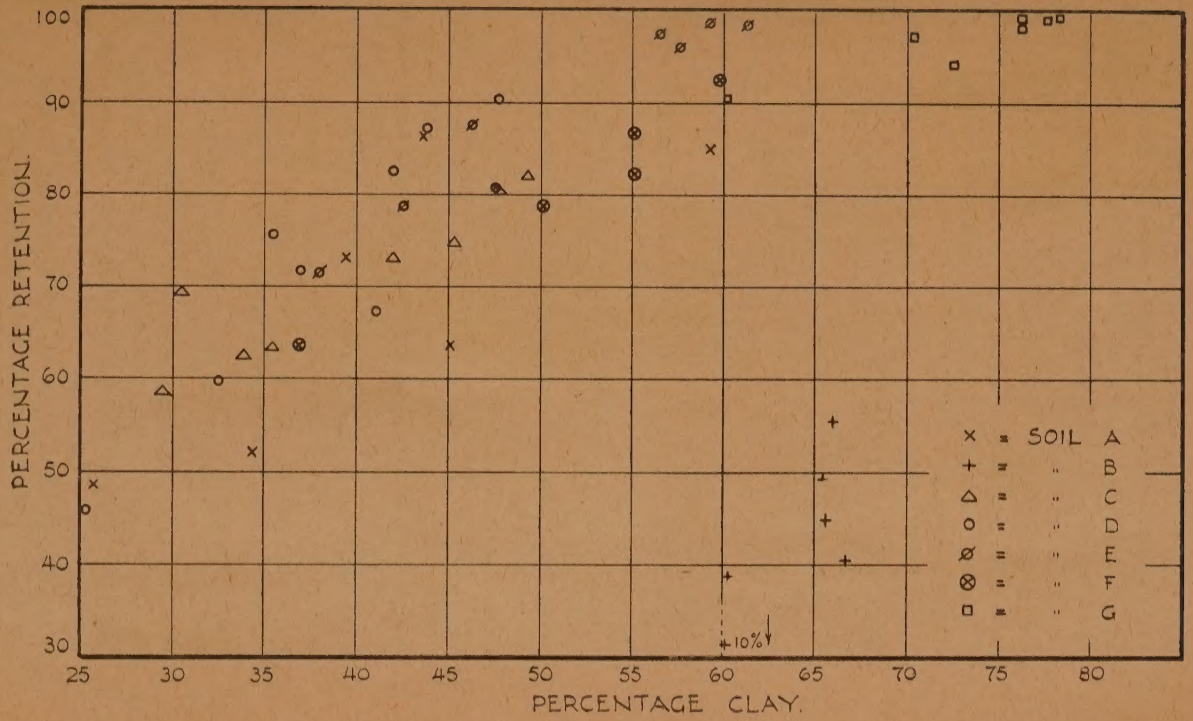
The degree of phosphate retention is very high in all soils and exceptionally high in the dolerite soil (soil G), over 90 per cent. of the phosphate being removed from solution by the surface soil and nearly complete removal by soils of the lower horizons of the profile. Retentions by all inland soils (i.e. soils C to G) are closely correlated with percentage of clay in the soils. The values for the alluvial soil A, while subject to slightly greater fluctuation, show the same relationship. (see fig. 1 and appendix). Values for the alluvial soil B however are widely different.

Regarding the inland soils, retention values are of the same order of magnitude in soils C, D, E and F, while those for the dolerite soil (G) are very much higher. This may be the explanation, at least in part, for the absence of response to treatment (as determined by girth increments of rubber trees) with ordinary dressings of phosphate fertilisers in areas covered by the dolerite soil, even though the readily soluble phosphate content of this soil, as determined by the conventional chemical method, is usually very low. Other

* The parent material of this soil type is not known with certainty. Owing to extremely deep weathering of rocks in the tropics it is often difficult to determine the parent material of different soil types, and the parent material of this particular soil type has not yet been definitely established.

Fig. 1

RELATIONSHIP BETWEEN DEGREE OF PHOSPHATE RETENTION AND PERCENTAGE CLAY.



inland soils similar to those represented by C, D, E and F, also having a low content of readily soluble phosphate, invariably respond to treatment, although the magnitude of the response is often much lower than that which would be expected on such phosphate deficient soils. No response to treatment has been detected on the coastal alluvial soils.

Although differences between average retentions for inland versus coastal alluvial soils do not correlate with clay content, within a single soil type at varying horizons there is a close relationship between the two characters describable by the regression

$$\log y = a + b \log m.$$

where y = percentage retention, m = percentage clay and a and b are constants.

The variability between one soil type and another, as for instance between soil B and other soils, suggests that some factor other than mechanical composition also governs the degree of retention in different soils. Soil behaviour with respect to phosphate is undoubtedly dependent to a certain extent on the chemical composition of the colloidal complex and this aspect of the problem will be discussed later. The reason for the wide difference between the degrees of retention in the two alluvial soils however is obscure. Their mode of origin is similar and one would expect that the chemical composition would not be so widely different. Moreover they exhibit similar morphological characteristics and in making a soil survey of the country they would normally be classified together in one soil series. Their different behaviour with respect to retention of phosphate requires further investigation.

Phosphate retention in all inland soils increases steadily with depth below the surface. Close correlation with clay content has been indicated and the present data do not allow for a separation of the two effects satisfactorily; it appears that we have to deal primarily with a clay effect.

Availability of the Phosphate Retained.

The values determined by the method described above gives a measure of the phosphate retained by the soil after treatment with a solution of phosphate. The total amount retained is not necessarily permanently fixed and a certain proportion of this must be easily available to plants. No chemical method is known whereby the amount of phosphate actually available to plants can be determined but methods have been described, and are used as standard methods, for

estimating the amount of readily soluble phosphate in soils. Values so obtained do not necessarily represent the actual amounts ultimately available to plants but they do indicate amounts which are easily available. Truog's method (18), slightly modified*, is normally used for this purpose in this laboratory and that proportion of the phosphate retained which is readily soluble was determined by this method. The experiments were carried out in such a way that it was possible to determine whether the amount of readily soluble phosphate in the soil varied with the time of contact of phosphate with soil. 50 gram samples of two soils were treated with solutions containing 25 and 50 milligrams P_2O_5, shaken for one half hour and allowed to stand overnight. The suspension was filtered and the soil then dried. The readily soluble phosphate in the soil was determined by the Truog method 2, 6, 12 and 30 days after filtering. Results are shown in Table II.

TABLE II

Soil	mgms P_2O_5 added to 50 grams soil	Readily soluble P_2O_5 (mgms per 50 grams soil)				Readily soluble P_2O_5 expressed as percentage of amount retained by the soil			
		after 2 days	after 6 days	after 12 days	after 30 days	after 2 days	after 6 days	after 12 days	after 30 days
M.	25	3.03	2.92	2.80	1.64	14.6	14.1	13.5	7.9
R.	25	3.98	3.84	3.65	2.67	24.3	23.4	22.3	16.2
M.	50	6.85	6.51	6.26	3.66	18.7	17.7	17.1	10.0
R.	50	8.04	7.86	7.21	5.34	30.2	29.5	27.1	20.1

Only a small fraction of the phosphate retained was recovered by the extracting solution used and the amount of readily soluble phosphate decreased with increasing time of contact with soil. The decrease was slight and almost neglible for the first 12 days but there was an appreciable decrease in 30 days. These results indicate that a very high proportion of added phosphate is so firmly held by local soils that it is not easily available to plants. This may be regarded as the fixed phosphate, which is in a difficultly available form and at least part of which must be completely unavailable. The amount of fixed phosphate increases with increasing time of contact with soil at the expense of the readily available

* The method was modified only to the extent that the extracting solution used was 0.01 N and not .002 N as suggested by Truog.

phosphate. The degree of fixation however varies according to the soil type. In soil M, a friable brownish red medium loam, over 70 per cent. of the phosphate added to the soil is fixed in a form which is not easily available to plants and the amount increases with time after application. In the sandy loam from Sungei Buloh, (soil R) the degree of retention is smaller, the percentage of readily soluble phosphate is greater, and the degree of fixation is only about 50 percent. Results are shown in Table III.

TABLE III

Soil	mgms P_2O_5 added to 50 grams soil	Phosphate retention %	After 2 days		After 6 days		After 12 days		After 30 days	
			Readily Soluble P_2O_5%	Phosphate fixed %	Readily Soluble P_2O_5%	Phosphate fixed %	Readily Soluble P_2O_5%	Phosphate fixed %	Readily Soluble P_2O_5%	Phosphate fixed %
M.	25	82.8	12.1	70.7	11.7	71.1	11.2	71.6	6.6	76.2
R.	25	65.5	15.9	49.6	15.4	50.1	14 6	50.9	10.7	54.8
M.	50	73.4	13.7	59.7	13.0	60.4	12.5	60.9	7.3	66.1
R.	50	53.2	16.1	37.1	15.7	37.5	14.4	38.8	10.7	42.5

On the basis of these results one would expect in a specified time after treatment with phosphate a bigger immediate response in soil R than in soil M. Observations to this effect were actually made when pot experiments were carried out, the results of which will be discussed later.

Availability of Various Phosphate Fertilisers in Soils

The phosphate fertilisers most commonly applied on local soils are superphosphate and Christmas Island Rock Phosphate, while other fertilisers such as Basic Slag, Bone Meal, Gafsa and Safaga phosphate are used on a much smaller scale. Experiments were carried out to determine the relative availability of these phosphatic fertilisers after application to local soils. Equivalent quantities (22.5 mgms P_2O_5 per 100 grams soil) of the various fertilisers in the dry state were added to 500 grams of soil, mixed thoroughly and placed in basins. The soil mass was moistened periodically and the readily soluble phosphate was estimated in aliquot samples by the modified Truog method after varying periods up to 146 days. For results see Table IV.

TABLE IV

Soil	Treatment	Readily Soluble Phosphate (milligrams P_2O_5 per 100 grams of soil) after:—										
		12 Days	19 Days	39 Days	62 Days	76 Days	90 Days	103 Days	118 Days	127 Days	133 Days	146 Days
M.	Super	3.93	3.20	1.97	2.42	2.86	3.22	2 16	2.67	2.36	2.58	2.23
R.	„	6.49	6.00	4.19	4.75	5.28	5.90	4.62	4.60	4.53	4.45	4.63
M.	Basic Slag	3.44	3.22	1.42	2.47	2.33	2.73	2.27	2.22	2.15	1.99	2.37
R.	„	6.94	6.82	5.12	4.43	5.59	5.69	4.12	4.15	4.40	4.48	4.63
M.	C.I. Rock	3.58	4.02	2.05	2.63	3.49	2.86	2.91	2.90	2.96	2.77	2.78
R.	Phosphate	4.10	5.04	3.51	3.34	4.29	3.20	4.28	4.32	4.08	3.83	4.32
M.	Safaga Rock	3.94	4.92	3.63	3.17	4.39	3.11	3.43	3.62	3.60	3.71	3.91
R.	Phosphate	6.18	6.72	5.31	4.20	5.64	4.74	3.63	4.72	4.82	4.78	4.75
M.	Gafsa Rock	4.28	4.88	2.96	2.97	3.28	3.03	2 02	2.22	2.56	2.60	2.71
R.	Phosphate	5.93	6.63	4.47	3.87	5.48	4.48	3.19	3.29	4.41	4.35	4.51
M.	Bone Meal	2.34	2.54	1.18	1.94	1.59	1.42	1.20	1.42	1.63	1.52	1.79
R.	„	3.80	4.62	2.96	2.74	3.52	3.07	2.26	2.62	3.24	2.96	2.96

The results again show that the amount of readily soluble phosphate decreases with increasing time of contact of fertiliser with soil but there are indications that a state of equilibrium may be reached after about three months, for the amount of phosphate extracted at intervals after this period is fairly constant. It is of interest to note that the readily soluble fraction, or the easily available phosphate, is of the same order of magnitude with all the phosphatic fertilisers applied, except Bone Meal which appears to have a lower degree of availability. It appears therefore that the relative availability of phosphatic fertilisers in local soils, as measured by a chemical method, is not dependent upon the solubility of the fertiliser. The amount of readily soluble phosphate is not greater in the soil treated with superphosphate than it is when the soil is treated with Christmas Island Phosphate and other insoluble phosphatic fertilisers.

The results reflect the difference between the two soils, confirming the statement made above to the effect that the relative availability, and therefore the degree of fixation, of phosphate is dependent on soil type. The amount of easily available phosphate is greater in soil R than in soil M no matter which phosphatic fertiliser is applied and this greater availability is apparent throughout the test period. Differences between qualities of phosphate (with the exception of Bone Meal) are not appreciable. Excluding Bone Meal, the proportion of the phosphate added which is easily available after 146 days varies between 10 and 17 per cent. in the Effingham soil (M) and between 19 and 21 per cent. in the Sungei Buloh soil (R).

Relationship between Degree of Retention and Concentration of Phosphorus Added

Varying amounts of KH_2PO_4 in 500 cc. of 1% CH_3COOH were added to 50 grams of soil. The mixture was shaken for one half hour, allowed to stand overnight and filtered. The amounts of phosphate in the filtrates were determined. For results see Table V.

TABLE V

mgms P_2O_5 added to 50 grams soil	mgms P_2O_5 in solution	
	Soil M	Soil R
25	4.30	8.72
50	13.31	23.38
75	24.30	39.20
100	37.50	56.50
125	53.75	78.75
150	75.00	98.50
175	98.60	122.00
200	117.50	145.83
225	141.12	169.25
250	170.50	194.50

The amount of phosphate retained by the soils increases with increasing concentration of the phosphate added. The rate of increase is fairly rapid at first but the degree of retention approaches a maximum when the concentration is about 180 to 200 milligrams P_2O_5 per 100 grams of soil.

The results are shown graphically in fig. 2 where the phosphate retained by the soil is plotted against the concentration of phosphate in solution after filtering. It will be observed that typical adsorption curves are obtained and Freundlich's equation fits the data for concentrations up to 100 milligrams P_2O_5 per 50 grams of soil or .007 mols per litre in solution.

Within the concentration range 25 to 100 milligrams P_2O_5 per 50 grams of soil, the slope of the logarithmic curves is typical of that usually observed in adsorption experiments and is almost equal for the two soils used in the tests.

Soil M. $y = 9.9\ z.^{509}$

Soil R. $y = 5.2\ z.^{526}$

y = mgms P_2O_5 retained. z = milligrams P_2O_5 in solution.

Adsorption in soil M is nearly twice as great (9.9 : 5.2) as in soil R for equal concentrations of phosphate in solution.

Fig 2

RELATIONSHIP BETWEEN AMOUNT OF PHOSPHATE RETAINED AND CONCENTRATION OF PHOSPHATE IN SOLUTION.

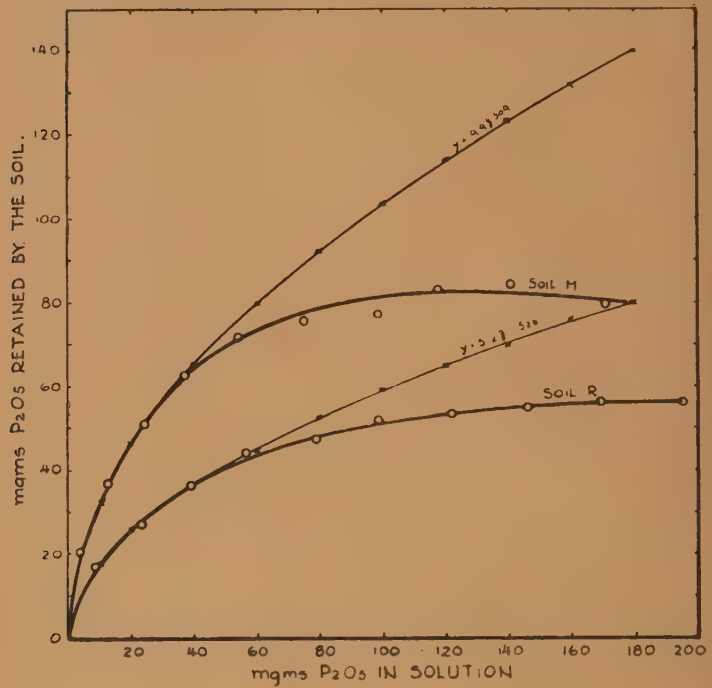
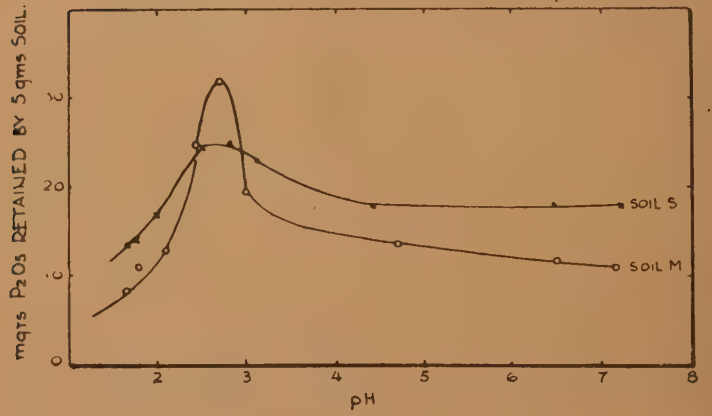


Fig 3

PHOSPHATE PETENTION AT DIFFERENT pH VALUES.



Adsorption in the higher concentration ranges did not occur according to the equation but similar falling off is frequently observed in adsorption experiments and this fact does not necessarily indicate that the reaction is not one of adsorption. It is now generally recognised that Freundlich's equation may hold only in limited ranges and it does not fit the data for all adsorption reactions.

The evidence suggests that the reaction between phosphate and soil is primarily one of adsorption. Yet the results in Table I show that equilibrium between phosphate solution and soils is reached very slowly and this casts a doubt upon the ascription of the phenomenon to adsorption. However it will be observed that the bulk of the phosphate added is retained very quickly; subsequent increases are slight and occur gradually. That the immediate removal of the bulk of the phosphate from solution is due to adsorption is indicated by the evidence adduced, while the slow attainment of equilibrium can be explained by the postulation that the phosphate ions adsorbed take part in further reactions after they have been removed from solution, being absorbed by the soil minerals forming equilibrium complexes. The retention of phosphate by soils cannot be accounted for by any single mechanism. It is evident that a variety of reactions may occur not the least important of which is adsorption by iron and aluminium complexes or clay minerals.

Phosphate Retention at Different pH Values

To 5 grams samples of soil the following solutions were added: x cc distilled water, y cc N/10 HCl or N/10 NaOH and 35 cc N/10 H_3PO_4. x and y were varied keeping $x + y = 65$ cc. The flasks were shaken in an end-over-end shaking machine and allowed to stand overnight before filtering. The solution was filtered through acid washed asbestos and the phosphate content of the filtrate was determined. Results are given in Table VI and shown graphically in Fig 3.

Both soils show a rather sharp maximum of phosphate retention about pH 2.6 to 2.7.

Britton (1) has shown that aluminium phosphate is precipitated from solution more acid than pH 5, separation of the precipitate beginning at pH 3.97, and Teakle (17) has shown that iron phosphate is least soluble around pH 3. A reasonable interpretation of these figures therefore appears to

TABLE VI

ccs. H_2O	ccs. N/10 HCl	mgms P_2O_5 added	Soil M		Soil S	
			pH of Solution	mgms P_2O_5 recovered	pH of Solution	mgms P_2O_5 recovered
—	65	77.04	1.65	68.71	1.65	63.85
25	40	„	1.80	66.41	1.75	63.12
45	20	„	2.10	64.51	2.00	60.37
65	—	„	2.45	52.44	2.50	52.81
	N/10 NaOH					
63	2	„	2.70	45.67	2.80	52.96
60	5	„	3.00	57.65	3.10	54.12
55	10	„	4.70	63.62	4.40	59.14
50	15	„	6.50	65.47	6.45	59.29
45	20	„	7.15	66.08	7.20	59.45

be as follows: The increase of retention as the pH alters from pH 4.5 to 3 probably reflects precipitation of aluminium phosphate, the sharp rise in soil M in the pH range 3 to 2.7 is probably due to precipitation of iron phosphate. As acidity increases below pH 2.5 both iron and aluminium come again into solution, and correspondingly the curves fall rapidly to low retention in this region.

If this interpretation be accepted the curves suggest that the effect of aluminium is nearly equal in both soils, while the effect of iron is appreciably greater in soil M than in soil S.

If the soil were treated with acid of increasing strength appreciable quantities of iron and aluminium would come into solution, especially when the pH of the solution is below 2.5. If, therefore, the phosphorus already present in the soil is in the form of iron or aluminium phosphate, increasing amounts of phosphorus should be liberated as the acidity increases. Tests were carried out by treating samples of four different soil types with HCl solution of various strengths. 125 ccs of the acid were added to 25 grams of soil and the suspension was agitated on a shaking machine for one hour. The pH of the suspension was then determined. the solution was filtered and the P_2O_5, aluminium and iron contents of the filtrate were estimated.

TABLE VII

	Strength of H Cl	pH of Suspension	P_2O_5 p.p.m.	Al p.p.m.	Fe p.p.m.		Strength of H Cl	pH of Suspension	P_2O_5 p.p.m.	Al p.p.m.	Fe p.p.m.
	.100N	1.20	1.85	321	78		.100N	1.23	1.20	285	89
	.075N	1.48	1.25	212	54		.075N	1.33	1.10	192	57
	.050N	1.60	1.05	206	34		.050N	1.53	0.80	187	32
Soil R	.025N	2.00	0.85	187	17	Soil H	.025N	1.93	0.50	150	24
	.010N	2.50	0.60	143	—		.010N	2.58	0.40	139	—
	.005N	3.13	0.50	59	—		.005N	3.13	0.25	94	—
	.001N	3.68	0.40	Trace	—		.001N	3.83	0.17	34	—
	.100N	1.20	0.80	150	35		.100N	1.20	2.50	157	33
	.075N	1.30	0.55	136	24		.075N	1.30	1.13	136	23
	.050N	1.55	0.38	126	10		.050N	1.50	0.70	123	6
Soil K	.025N	2.00	0.28	121	2	Soil S	.025N	2.00	0.45	117	—
	.010N	2.75	0.15	121	—		.010N	2.60	0.30	108	—
	005N	3.15	0.10	108	—		.005N	3.10	0.15	94	—
	.001N	3.75	0.10	55	—		.001N	3.80	0.15	25	—

The results in Table VII do indicate a slight but steady increase in the phosphate content of the filtrate with increasing acidity. The amounts of iron and aluminium in solution also increase with increasing concentration of HCl. The higher the acidity, the greater is the concentration of P_2O_5 in relation to the concentrations of Al + Fe. When the concentrations of P_2O_5, and of aluminium plus iron, are plotted against pH (fig. 4), the general similarity of the slopes of the curves obtained in the pH range below 3.0 suggests a relationship between the phosphate and the two soil minerals brought into solution.

The results tend to indicate that phosphates of iron and aluminium are present in the soil and that at least part of the phosphorus is locked up in this form. However it is not considered that the rapid retention and fixation of phosphate when applied to soils are due to immediate precipitation of iron and aluminium phosphates. The results in Table VII show that very little iron is found in the soil solution until a high acidity is reached. The majority of local soils have a pH varying from 4 to 5 and within that range free Fe and Al ions are not present to any appreciable extent. Immediate precipitation of iron and aluminium phosphate is therefore unlikely. Heck (9) and many others consider that the active iron and aluminium in soils exist in the forms of hydrated oxides. The suggestion that the immobilization of the phosphate first occurs by adsorption on the surfaces of the colloidal particles of hydrated alumina and ferric oxide with subsequent chemical reaction to form insoluble phosphates of iron and aluminium is more consistent with the data.

Retention of Phosphate in the Presence of Nitrogenous Fertilisers

Tests were carried out to determine whether the degree of phosphate retention is affected when nitrogenous fertilisers are applied with the phosphate. To 50 gram samples of soil 10 ccs of 1% $(NH_4)_2SO_4$ and sufficient of an 1% solution of CH_3COOH to moisten the soil, were added. 25 milligrams P_2O_5 as KH_2PO_4 in 1% solution of CH_3COOH were then added, bringing the final volume to 500 ccs. The suspension was agitated in the shaking machine for one half hour and allowed to stand overnight. The H ion concentration and P_2O_5 content of the filtrate were then determined.

Fig. 4.

AMOUNTS OF PHOSPHOROUS AND OF Al + Fe RELEASED BY ACID TREATMENT.

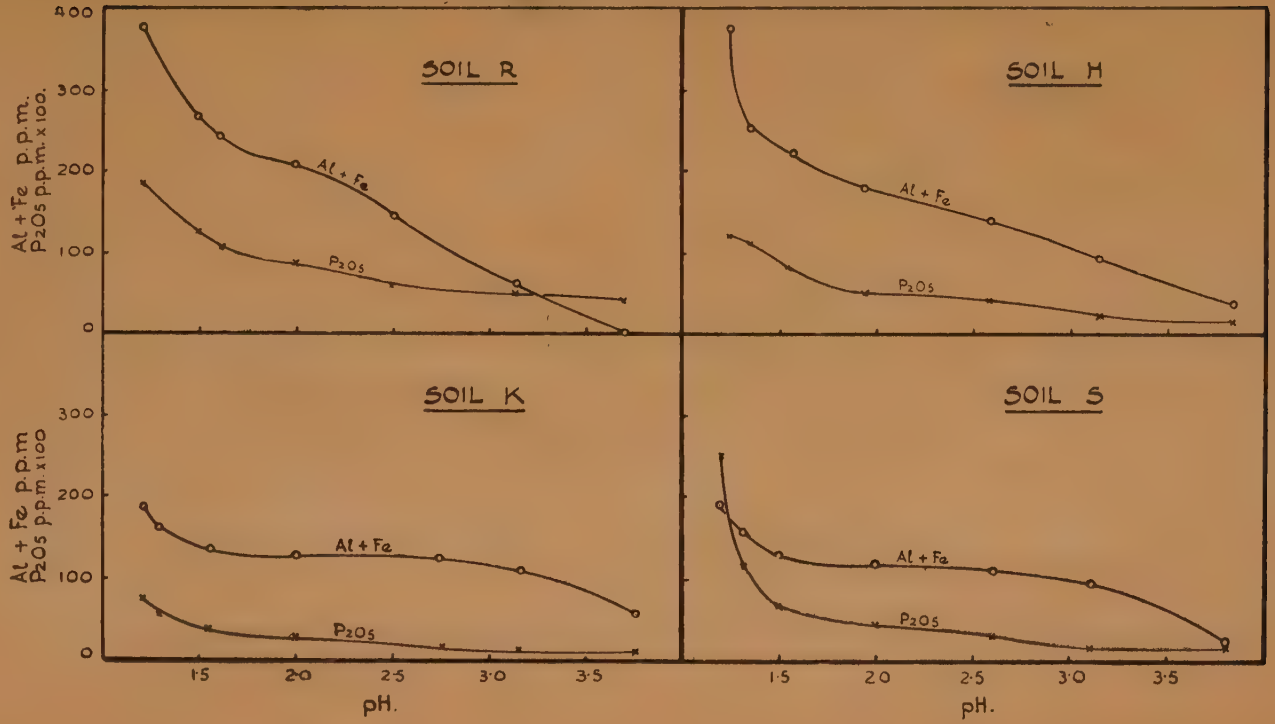


TABLE VIII

Soil	mgms. P_2O_5 added to 50 grams soil	In the absence of $(NH_4)_2SO_4$			In the presence of $(NH_4)_2SO_4$		
		pH of filtrate	mgms P_2O_5 recovered	Percentage retention	pH of filtrate	mgms P_2O_5 recovered	Percentage retention
M.	25	3.10	2.53	89.9	3.15	3.35	86.6
R.	„	3.00	5.38	78.5	3.05	6.32	74.7
G.	„	3.23	1.45	94.2	3.30	1.95	92.2
A.	„	3.03	4.43	82.3	3.10	5.20	79.2

The results in Table VIII show that the recovery of phosphate is enhanced in the presence of ammonium sulphate in each of the four soils tested. The same observation was confirmed when the experiment described above was modified as follows:—50 gram samples of soil were treated with the following solutions; (*1*) 20 ccs water, (*2*) 10 ccs water + 10 ccs of 1% $(NH_4)_2SO_4$, (*3*) 20 ccs of 1% $(NH_4)_2SO_4$, (*4*) 10 ccs water + 10 ccs of 1% $NaNO_3$, (*5*) 20 ccs of 1% $NaNO_3$. The soils were then left in the flasks for eight days after which period 500 ccs of 1% CH_3COOH containing 25 milligrams P_2O_5 as KH_2PO_4 were added. The flasks were shaken for one half hour and allowed to stand overnight. The pH and P_2O_5 content of the filtrates were determined as before.

TABLE IX

Treatment	mgms. P_2O_5 added to 50 grams soil	Soil M			Soil R		
		pH of filtrate	mgms P_2O_5 recovered	Percentage retention	pH of filtrate	mgms P_2O_5 recovered	Percentage retention
1	25	3.10	3.18	87.3	3.00	6.17	75.3
2	„	3.20	4.06	83.8	3.05	6.46	74.2
3	„	3.20	4.45	82.2	3.05	6.52	73.9
4	„	3.10	3.33	86.7	3.00	6.70	73.2
5	„	3.10	3.47	86.1	3.00	6.72	73.1

The results in Table IX again show that the recovery of phosphate is enhanced in the presence of nitrogenous fertilisers, but the increase is only slight in soil R. In the Effingham soil (M), ammonium sulphate has a greater effect than Sodium Nitrate. The general trend of the results indicate that the degree of retention of phosphate is reduced in the presence of nitrogenous fertilisers and it would appear therefore that more phosphate would be available to the plants immediately after application, if nitrogenous and phosphatic fertilisers are applied at the same time.

In order to test whether nitrogenous fertilisers have any effect on the availability of phosphate in soils not treated with a phosphatic fertiliser, samples of soil were treated with solutions of ammonium sulphate and sodium nitrate as in the above experiment. The soils were then allowed to reach the air dried condition and the readily soluble phosphate was determined by the modified Truog method using N/100 H_2SO_4 buffered to pH_3 with ammonium acetate as extractant.

TABLE X

	Treatment	Readily soluble phosphate p.pm. P_2O_5	
		Soil M	Soil R
1.		1.9	5.9
2.	$(NH_4)_2SO_4$ (1)	2.1	7.1
3.	-do- (2)	2.3	7.3
4.	$NaNO_3$ (1)	2.6	8.1
5.	-do- (2)	3.2	8.3

The results in Table X indicate that when nitrogenous fertilisers are applied to soils the availability of the native phosphate in the soil is slightly enhanced. Marais (12) points out that the effect of various nitrogen compounds on the availability of insoluble phosphate has been carefully studied by a number of workers, more particularly Russian workers. He states that all the results agree in general that ammonium sulphate enhances the availability of insoluble phosphates, but adds that other nitrogen compounds are less effective. Marais also observes that it has been definitely established that nitrification affects the availability of insoluble phosphate.

Williams and Stewart (19) comparing the effects of ammonium sulphate and ammonium chloride solutions on the recovery of added phosphate found that the sulphate solutions extracted much more than the chloride solution. Discussing the manner in which salts can affect the solubility of phosphate in soils they produce evidence to show that the nature and concentration of the anions present rather than the ammonium concentration are the most important factors. They hold the view that the effect can be explained on the basis of anionic exchange, the sulphate ions having a greater displacing power because they are divalent.

Effect of Exchangeable Bases on Phosphate Retention

It is clear that the degree of retention of phosphate by soils is dependent on a number of factors. There is considerable evidence in the literature to show that anion exchange reactions are of considerable importance. It is held that phosphate retention is also dependent to a certain extent upon the cation exchange reaction. In order to determine to what extent the retention of phosphate in local soils was governed by various exchangeable cations the following experiment was carried out using soils M and R.

The total exchangeable bases in the two soils was first determined. 50 gram samples of soil were then treated with solutions of $CaCl_2$, $MgCl_2$, KCl and NaCl, in quantities of 10 equivalents of salt in 100 ccs solution for one equivalent of active base found in 50 grams of soil. The suspension was allowed to stand for one hour and then filtered and washed until free of chlorides. The soil was air dried and ground up in a mortar with a wooden pestle. Solutions of KH_2PO_4 containing 5, 10, 15, 20 and 25 milligrams P_2O_5 were then added. The soil and solution were shaken for one half hour and allowed to stand overnight. The P_2O_5 content of the filtrate was determined.

TABLE XI

mgms P_2O_5 added to 50 grams soil	mgms P_2O_5 recovered in 500 ccs of the filtrate after Soil was treated with:—									
	CaCl		KCl		NaCl		MgCl		No treatment	
	Soil M	Soil R	Soil M	Soil R	Soil M	Soil R	Soil M	Soil R	Soil M	Soil R
5	.17	.31	.21	.35	.23	.54	.19	.38	.18	.41
10	.80	1.21	.98	1.42	.99	1.73	.82	1.56	.97	1.85
15	2.01	2.78	2.30	3.15	2.34	3.63	2.05	3.23	2.47	4.09
20	3.55	5.10	4.38	5.19	4.35	6.13	3.92	5.25	4.40	6.46
25	5.90	6.50	6.46	7.88	6.33	8.60	5.99	7.57	6.67	8.90

The results in Table XI show that the degree of retention was slightly but consistently greater in the Ca and Mg soils, while no consistent difference is apparent between the K, Na and untreated soils. Ravikovitch (16) also found that the exchangeable cations, Ca and Mg had the greatest effect on retention or fixation of phosphate and Na cations were least effective. However, the trend of the present results tend to indicate that exchangeable bases play only a minor role in influencing the degree of retention of phosphate in Malayan soils.

Summary

1. The degree of phosphate retention in a variety of Malayan soils was determined. All local soils have a very high capacity for removing phosphate from solution and retaining it in a difficulty available form. Most of the sedentary inland soils behave similarly, and in these, the degree of retention of phosphate is closely correlated with the percentage of clay in the soil. The coastal alluvial soils do not show the same close correlation although, within each soil profile, there is a close correlation between the degree of retention and clay content in the various horizons of the profile. Up to retention values of 95% this relationship is best expressed by the equation $\log y = a + b \log m$ where y = percentage retention, m = percentage clay and a and b are constants.

2. The absence of correlation between the degree of retention and clay content as between soil types suggests that some factors other than mechanical composition also govern the degree of retention of phosphate.

3. Only a small fraction of the phosphate retained is easily available to plants. As the time of contact between the phosphate and soil increases the amount of readily available phosphorus decreases.

4. After the addition of phosphates, the readily soluble phosphorus fraction in any one soil, as determined by a conventional chemical method, is roughly the same whether soluble or insoluble inorganic forms of phosphate are applied. The suggestion that soluble phosphates are more easily available to plants growing in Malayan soils is not supported by the experimental evidence. The degree of fixation and therefore the relative availability of phosphate are dependent on soil type rather than on the forms of inorganic phosphate applied.

5. In order to ensure the most efficient utilization of phosphate, the characteristics of the soil type must be considered and the quantities applied varied accordingly. In view of the marked immobilization of the phosphorus it is evident that quantities of fertiliser larger than those normally applied are essential in many of the soil types of Malaya in order to provide adequate supplies of available phosphate.

6. The amount of phosphate retained by soils increases with increasing concentration of the phosphate added but not in the same proportion. For a given soil the curve for amount of phosphate retained plotted against concentration of phosphate in solution is similar to adsorption curves in general, being describable by the empirical Freundlich adsorption formula up to moderate concentrations.

7. Retention of phosphate varies with acidity of the soil in a definite manner (fig. 3) with a marked maximum about pH 2.6 to 2.7. The curves can be reasonably explained in terms of the known effect of pH on solubility of iron and aluminium phosphates.

8. The evidence suggests that the reaction between phosphate and soil is primarily one of adsorption, but the phosphate ions absorbed take part in further reactions after they have been removed from solution, being absorbed by the soil minerals forming equilibrium complexes. Results indicate that iron and aluminium play an important role. The degree of immediate retention of phosphate is primarily governed by the content of colloidal fraction, but it is considered that the degree of ultimate fixation, and therefore the relative availability of the phosphate retained, are largely dependent on the contents of iron and aluminium, and the forms in which these minerals are present in the soil.

9. Nitrogenous fertilisers enchance slightly the availability of phosphate in soils. It may be expected therefore that the efficiency of phosphate fertilisers will be improved when these are applied with a nitrogenous fertiliser.

10. Exchangeable bases play only a minor role in influencing the degree of retention of phosphate in Malayan soils.

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STATISTICAL APPENDIX

BY

H. Fairfield Smith

Correlation of phosphate retention with clay, depth, silica, iron and aluminium. (Ref. Sec. " Retention of phosphate by different soil types " on p. 5 and Fig. 1).

As is inevitable for any character approaching a limit (100 per cent. retention) the regression of phosphate retention on any soil character shows curvature, and investigation of multiple correlation will be greatly simplified if the correlations can be rectified. As noted in the text, the regression of logarithm of phosphate retention on logarithm of clay content of the soil appears to be linear so long as phosphate retention is less than about 93 per cent. Such a regression indicates a fairly simple relationship, viz. that *relative* increments of phosphate retention for *relative* increments in quantity of clay tend to be constant for a given soil type. By analogy with other work which depends on observation of proportions, (e.g. biological assays based on proportions of animals affected by varying doses) one might guess that here also regressions might be most accurately evaluated if the " doses " of phosphate were so arranged that observed retentions would vary around 50 per cent., when also they would be analysed on the basis of some relatively simple transformation such as that noted above. However since a quarter of the observations under present investigation exceed 93 per cent. retention another transformation was sought which would rectify the data over the whole range. Of several functions tried, transformation of per cent. retentions to probits (Fisher and Yates: Statistical tables for biological research, Table IX) was outstandingly the most successful.

Since, on the theory underlying probits as usually used, their accuracy diminishes as the percentages from which they are derived approached 0 or 100 per cent., it is usually advisable to weight data expressed in this form. The present application is however empirical, and after evaluating regressions on clay and depth for each soil individually it was found that all variances for deviations from regressions were homogeneous, those for soils E and G (i.e. those with greater than 93 per cent. retention) being not greater than the average of the others. The following analyses are therefore based on per cent. phosphate retention transformed to probits, with each observation given equal weight.

Regression on Clay and Depth

The behaviour of soil B is outstandingly different from the others. It has therefore been excluded from the analysis of this section. The other 6 soils, for which samples were taken from 6 to 8 profile horizons, gave analysis of variance of phosphate retention probits as follows,

depth being measured on a geometric scale, 0-3″ = 0, 3-6″ = 1, 6-12″ = 2, 12-24″ = 3 etc.; and clay being taken as percentage of dry soil:

	d.f.	M.Sq.
Between means for each soil:		
†Regression on clay ..	1	10.8556
Partial regression on depth ..	1	.1946
Deviations from regression ..	3	.3875
Between horizons within soils:		
†Average regression on clay ..	1	6.8754
Av. partial regression on depth ..	1	.1400
*Heterogeneity of regressions on clay ..	5	.1685
*Heterogeneity of partial regressions on depth ..	5	.1371
Remainder (deviations from regressions within soils) ..	24	.01425

These figures show that an overwhelming amount of the variance of phosphate retention of these samples can be accounted for by variation in clay content. (Total sum of squares—for 41 degrees of freedom—being 21.0981, the overall correlation coefficient $r = (17.4448/21.0981)^{1/2} = .909$). Variation of regressions between horizons of individual soils, and correlation with depth and variations thereof, each account for about equal small, albeit highly significant, shares. No explanation of the depth effect could be found among the other characters observed.

Correlation with Silica, Iron and Aluminium

For variation between horizons within soils, after allowing for the regression on clay, no residual correlation with silica, iron or aluminium can be detected.

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* i.e. differences between regressions for individual soils.

† The average regressions on clay between and within soils may be differently partitioned as follows:

	d.f.	M.Sq.
Overall average regression on clay ..	1	17.4448
Difference of regression between soils and average regression within soils ..	1	.2862

For variation between soils it is useless to attempt to seek a correlation with four variates among only six values. Therefore for this aspect of the data we consider correlation between means of all soils available viz. the above six, plus B and 3 others (M, R and G. 2.) for which samples from only one horizon were available. All of the last four lay outside the correlation surface of retention: clay exhibited by the six soils discussed in the preceding section (two lying above and two below), and the mean retentions of these ten soils show little correlation with clay. Analysis of variance for multiple regression on clay, iron and aluminium gives:

	d.f.	M.Sq.	P
Regression on clay ..	1	.281	high
Partial regressions on iron and aluminium ..	2	1.144	.02
Remainder ..	6	.149	

The regression coefficients on iron and aluminium are about equal, being respectively

$.062 \pm .023$ and $.055 \pm .027$

There is no correlation with silica.

RETENTION OF PHOSPHATE BY MALAYAN SOILS

II. PENETRATION IN SOILS AND ABSORPTION BY PLANTS

BY

G. OWEN

Evidence has been produced to show that the degree of retention of phosphate by Malayan soils is very high (see page 6 and Fig. 1). Much of this phosphate held by the soil is fixed in a form which is difficultly soluble and for practical purposes of little use to plants. The efficiency of phosphate fertilisers is greatly reduced, not only because of their conversion to relatively insoluble forms but also because the phosphate does not penetrate, to any appreciable extent, into the soil mass, so that it comes in contact with only the surface roots. This failure to penetrate into the lower horizons of the soil profile is of course due to the high capacity of the soil for retaining phosphate so that when phosphate fertilisers are applied they are held firmly by the soil at or near the point of contact. Obviously better efficiency can be expected therefore, if the fertiliser is worked into the soil. Midgely (5) found that superphosphate worked into the soil gave an increase in total yield of grass and weeds of 71.5% more than a similar amount of superphosphate applied on the surface. Feilitzen (2) working with Swedish moor soils, found that Thomas Slag, if mixed with the soil to a depth of 6 inches increased the yield of green substance of a crop of peas 42% over that obtained when the slag was harrowed into the surface inch.

Soils vary greatly as to the extent to which they permit the penetration of soluble phosphate. Heck (4) comparing some American soils with Hawaiian laterites found that least penetration occurred in the latter, the soluble phosphate added being held within the top half inch of soil. Sen (6) and Harrison and Das (3) report only slight penetration in the calcareous soils of India. Similar observations regarding the lack of downward movement of phosphate in soils have been made by Crawley (1), Stephenson and Chapman (8) and others.

Experiments were carried out to determine the extent of downward movement of phosphate in Malayan soils. Glass tubes, 2 inches in diameter and 24 inches long were packed with soils in such a way that a column of soil 12 inches long was obtained. The bottom of the tube was plugged with a pad of glass wool over a rubber stopper, through which passed

a narrow glass tube for drainage. The soil column was moistened to point of saturation with distilled water (about 300 ccs). The following day a solution of KH_2PO_4 was poured over the top of the soil column. The amount of phosphate applied was at the rate of 22.5 milligrams of P_2O_5 per 100 grams of soil, which is equivalent to 450 lbs. P_2O_5 or about 10 cwts. concentrated superphosphate per acre. 300 ccs of water were added at intervals and all the leachates were collected and the phosphate content determined. The experiment was carried out in triplicate on each of two soils i.e. Soils M and R.

After about one month the addition of water was discontinued and the soil was allowed to reach the air dried condition. The columns were gently pushed out of the tubes, the top half divided into one inch sections and the lower half into two inch sections. The total phosphate in each section was determined. From these values, the proportion of added phosphate held in each horizon was calculated by subtracting the amount of phosphate in untreated soil. No correction for loss by drainage was necessary since only traces of phosphate was found in the leachates. Results, expressed as percentages are shown in Table XII.

TABLE XII

Penetration of Phosphate in Soils

Phosphate added in solution: 22.5 mgms P_2O_5 per 100 grams soil

Depth in (inches)	Amount of total P_2O_5 retained in the soil expressed as percentage of amount added					
	Soil M			Soil R		
	Tube I	Tube II	Tube III	Tube I	Tube II	Tube III
0- 1	35.6	36.0	28.5	29.7	39.1	31.9
1- 2	22.8	28.0	22.3	26.6	32 5	24.1
2- 3	16.6	18.4	11.6	27.0	17.4	23.1
3- 4	12.3	11.4	8.4	18.8	5.5	16.6
4- 5	7.4	8.9	4.7	2.6	—	6.4
5- 6	4.5	3.3	4.0	.3	.3	1.1
6- 8	1.6	6.7	6.4	.2	1.1	—
8-10	1.2	5.1	5.8	.4	2.4	2 6
10-12	2.1	3.5	5.2	.8	1.4	2.8

Under the conditions of this experiment the soluble phosphate applied as a solution penetrated to a depth of about 4 to 5 inches in both soils. Over 30% is held in the first inch, over 50% in the first two inches and more than 70% in the top three inches. Considering that the phosphate was applied in solution and that the soils in the tubes were by no means as compact as they are under actual field conditions, the degree of penetration is surprisingly small. It is reasonable to assume that under field conditions the same soils will allow much less penetration than under the laboratory conditions described.

Similar experiments were carried out with five soil types and using five different forms of phosphate. The soil columns were set up as in the previous experiment and the phosphates, in quantities equivalent to 500 lbs. superphosphate (18%) per 2,000,000 lbs. soil were applied in the solid form on the surface of the soil column. Water was added daily. The sampling, and analysis of the samples were done as in the previous experiment, except that in this series the first and second half inch of the column were sampled and analysed separately.

The soils used for this test were:—(1) a friable medium loam from Effingham Estate, Selangor (soil M), (2) a fine sandy loam from Sungei Buloh, Selangor (soil R), (3) a granite loam from Scudai, Johore (soil K), (4) a heavy alluvial clay loam from the Dindings, Perak (soil H) and (5) a dolerite soil from Kuantan, Pahang soil S). To soils H and S only superphosphate was applied, but the remaining three soils were treated with five different phosphate compounds. The forms of phosphate applied were:—superphosphate (18%), nicifos B (17.9%), diammonium hydrogen phosphate ($(NH_4)_2HPO_4$), disodium hydrogen phosphate (Na_2HPO_4) and potassium dihydrogen phosphate (KH_2PO_4). The results are shown in Table XIII.

Only traces of phosphate were found in the leachates indicating that almost all the phosphate applied was firmly held by the column of soil. Moreover, nearly all the phosphate was retained in all soils within three inches of the point of application. The distribution of the phosphate within this three inch horizon varied according to soil type and the form in which the phosphate was applied. The alluvial soil from the Dindings, Perak (soil H) showed the greatest resistance to the downward movement of phosphate, 75% of the phosphorus failing to penetrate beyond the top half inch of soil and 90% being held within an inch of the

TABLE XIII

Penetration of various phosphate compounds in soils.

Phosphate applied in solid form, in quantities equivalent to 500 lbs. superphosphate per acre.

(Depth in inches)	Amount of total P_2O_5 retained in soil expressed as percentage of amount added																
	Superphosphate					Nicifos B			Di-Ammonium Hydrogen Phosphate			Di-Sodium Hydrogen Phosphate			Potassium Di-hydrogen Phosphate		
	Soil H	Soil K	Soil M	Soil R	Soil S	Soil K	Soil M	Soil R	Soil K	Soil M	Soil R	Soil K	Soil M	Soil R	Soil K	Soil M	Soil R
0-½	74.7	55.2	70.6	49.7	66.8	28.4	44.7	20.9	32.9	39.5	19.7	23.5	35.9	8.6	22.7	40.0	39.0
½-1	15.4	17.8	17.6	21.1	7.3	21.7	29.2	25 2	23.5	29.8	23.2	15.9	22.7	15.6	18.1	25.4	22.9
1-2	1.9	7.0	4.9	13.7	11.7	31.4	22.5	41.9	31.7	29.5	35.9	19.4	31.1	44.4	34.0	23.5	14.0
2-3	3.1	—	4.0	6.3	—	5.7	8.9	2.5	6.3	7.3	14.6	19.0	14.0	16.2	14.3	5.4	3.2
3-4	3.1	.6	6.1	2.9	2.9	2.5	6.0	—	—	10.1	1.9	7.3	6.3	—	4.8	3.8	1.6
4-5	1.9	1.0	7.8	1.3	1.0	—	7.3	1.0	—	5.4	—	3.8	5.4	—	5.4	5.7	—
5-6	1.0	.3	6.1	4.8	1.0	.3	7.6	.6	3.2	5.4	2.9	1 9	6.7	—	2.5	5.4	2.2
6-7	.6	—	3.2	1.3	—	—	—	—	2 2	2.5	—	—	7.0	—	.6	5.1	.3

surface. The degree of penetration was also very small in the dolerite soil from Pahang (soil S) and in the friable medium loam from Selangor (soil M), the proportion of applied phosphate held in the first inch of these soils varying from 65 to 86% depending on the quality of phosphate. Slightly more efficient penetration was observed in the granite soil from Johore (soil K) and in the fine sandy loam from Sungei Buloh (soil R) but even in these two soils the major portion of the phosphate added was held in the top two inches.

The results presented show small but consistent differences in the penetrating power of the various forms of phosphates. They clearly demonstrate the less efficient penetration of superphosphate as compared with the other soluble phosphate compounds. This agrees with results obtained by Midgley (5) working with American soils. A greater proportion of the Nicifos B and of di-ammonium hydrogen phosphate penetrate beyond the first inch of soil, but over 80% of these is held in the top two inches. The phosphate of potassium has a slightly better penetrating power while di-sodium hydrogen phosphate is least readily retained by the soils, an appreciable proportion of this penetrating into the third inch of the soil column. Similar observations were made by Midgley (5) and by Spencer and Stewart (7).

Having observed that the extent to which local soils permit the penetration of soluble phosphates is exceedingly small even under ideal conditions, it was then decided to determine whether the degree of penetration varied according to the particle size or fineness of the fertiliser. Superphosphate was separated into three fractions as follows:—

(1) Particles with diameter of 0.1 mm or less.

(2) ,, ,, ,, between 0.1 mm and 0.5 mm.

(3) ,, ,, ,, ,, 0.5 mm and 2.0 mm.

The P_2O_5 content of each of the three fractions was determined. A known weight of each fraction was applied in the solid form on the surface of soil columns as in the previous experiment. Water was added daily and the leachates collected as before. For this experiment only soil M was used and the test was carried out in duplicate for each of the three samples of superphosphate.

TABLE XIV

Penetration of phosphate in soils

Superphosphate of various degrees of fineness applied in the solid form. (Soil M)

Depth (in inches)	Total P_2O_5 retained expressed as percentage of amount added.			"Available" P_2O_5 (p.p.m.)		
	Particle size			Particle size		
	< 0.1 mm	0.1 mm to 05 mm	05 mm to 2 mm	< 0.1 mm	0.1 mm to 05 mm	05 mm to 2 mm
0-½	52.7	49.4	47.4	96	207	215
½-1	20.1	17.0	15.3	41	54	56
1-2	9.8	7.8	6.1	9	8	6
2-3	5.6	4.6	2.6	2	3	2
3-4	1.6	3.9	1.0	tr	2	2
4-5	2.4	2.6	1.0	„	2	2
5-6	4.2	2.3	1.0	„	2	2
6-7	2.1	2.3	1.3	„	2	tr
7-8	4.1	1.5	—	„	2	„

The results in Table XIV again show that there was very little penetration of phosphate below the top three inches of soil and that the major portion was held within one inch of the surface. Furthermore, it will be observed that as much as 50 per cent. of the phosphate applied was retained within half an inch from the point of contact.

The results of this experiment indicate that the degree of penetration of superphosphate is independent of the size of particles applied. It is interesting to note however that the amount of readily soluble phosphate is greater in the soils to which the coarser fractions have been applied. In other words, the phosphate held near the point of contact of fertiliser and soil is rather more easily available when the coarser fractions of the superphosphate are applied. This is not surprising since the coarser particles provide a smaller surface in direct contact with the soil colloid, and therefore the degree of absorption of phosphate by this colloid will be less in comparison with that which occurs when the finer particles are applied. The results presented herein are not sufficiently comprehensive to allow for a definite statement on the relative merits of coarse and fine grained fertilisers from the point of view of availability, but there is evidence to indicate that the coarser material may be more slowly fixed

in a difficulty available form. The results serve to indicate that this particular aspect of the problem merits further investigation.

Uptake of Phosphate by Plants

In the experiments described on the previous pages the factors influencing the retention of phosphate by local soils have been considered and the movement within the soil, of phosphates applied as fertilisers, has been studied. Such investigations form a background to a study of the uptake of phosphate by plants, both in pots and in the field, and of the effect of phosphate on growth and yield of rubber trees.

As a preliminary to more extensive pot culture work which is to be taken up, miniature pot experiments were carried out using paddy seedlings as indicator plants. The main object of the first experiment was to determine to what extent the phosphate retained by the soil was available to plants, and to determine whether the amount of readily soluble phosphate, as determined by the conventional laboratory method used in this laboratory, did actually represent the amount that is readily available to plants. Two soils were used (soils M and R) and the treatments were as follows:—

(a) Soil untreated.
(b) 25 milligrams P_2O_5 per 50 grams soil added in solution.
(c) 50 milligrams P_2O_5 per 50 grams soil added in solution.
(d) 25 milligrams P_2O_5 per 50 grams soil added in solution and the readily soluble phosphate extracted.
(e) 50 milligrams P_2O_5 per 50 grams soil added in solution and the readily soluble phosphate extracted.
(f) No phosphate added: readily soluble phosphate extracted.

In treatments d, e and f, the readily soluble phosphate was removed by extraction with N/100 H_2SO_4 buffered to pH3 with ammonium acetate.

For each treatment, a known weight of soil was mixed with acid washed sand and placed in a small container. Another container was filled with acid washed sand. Paddy seeds were sown and a solution containing 200 p.p.m. of N and of K_2O was added once weekly. The crop was harvested before reaching maturity 3 months after sowing; roots and leaf portions were separated and the total P_2O_5 in both samples was determined. The experiment was carried out in duplicate. Results are shown in Table XV.

TABLE XV

Uptake of phosphate by plants

Treatment	Soil M			Soil R			Sand		
	Total Dry Wt. (grams)	Ash (mgms)	P_2O_5 (mgms)	Total Dry Wt. (grams)	Ash (mgms)	P_2O_5 (mgms)	Total Dry Wt. (grams)	Ash (mgms)	P_2O_5 (mgms)
(a)	0.83	77.6	6.2	0.85	89.9	6.2	0.45	29.7	6.2
(b)	0.65	61.2	10.8	0.74	75.3	11.7			
(c)	0.63	63.4	16.4	0.74	88.0	18.3			
(d)	0.68	66.6	8.4	0.49	50.9	5.6			
(e)	0.65	58.1	10.6	0.51	50.9	6.6			
(f)	0.89	80.2	6.2	0.74	74.9	6.3			
S.E. $\pm$	0.037	3.90	0.31	0.037	3.90	0.31			

Results of this particular experiment show no correlation between yield and the amount of phosphate taken up by the plants Figures showing the phosphate content of the plants are more interesting and instructive. Comparing the values for untreated soil and for sand it will be observed that the amount of phosphate taken up from untreated soil was negligible indicating that the native phosphorus in the soil is in a form which is not easily absorbed by plants.

Regarding the phosphate added it will be seen that only a small proportion of this was utilised by the plants during the period of the experiment (3 months). The amount absorbed varied between 6 and 8 per cent. of the amount added. When the readily soluble phosphate was previously removed by extraction with N/100 H_2SO_4, the amount absorbed by the plants was much less, indicating that phosphate insoluble in the standard extracting solution was less easily available. The effectiveness of the extracting solution in removing the readily available fraction appears to depend on soil type. This fraction seems to have been almost completely removed from the Sungei Buloh soil (soil R) while in the heavier soil M, some phosphate was still taken up by the plants (although in reduced amounts) even after extraction of the readily soluble fraction. In other words, the effect of the removal of the readily soluble fraction was greater in the Sungei Buloh soil. This was to be expected in view of earlier results which showed that a much greater proportion of the phosphate retained after treatment was removed from soil R than from soil M by extraction with N/100 H_2SO_4. (see Table III). The fact that the phosphate taken up by the plants from soil R was greater than that from soil M supports to a certain extent, the assumption that the readily soluble phosphate as determined by the conventional method represents the available phosphate, but the actual values are not necessarily a correct indication of the amounts actually available to plants. The agreement between the measured and actual amounts is closer for some soils than others.

If we assume that the phosphate fraction which is not removed by extraction with dilute sulphuric acid is the " fixed " phosphate it may be stated, judging from the results of the above experiment, that the phosphate fixed by the Sungei Buloh soil, although less in amount, is apparently more difficultly available than the " fixed " phosphate in soil M. This indicates that various factors responsible for fixation are not equally effective and that phosphate fixed in some forms is almost completely unavailable to plants, while

in certain soils, as for instance in soil M, part of the phosphate fixed may be in a form which can still be taken up by plants.

Uptake of Phosphates by Plants from Soils Treated with Various Phosphatic Fertilisers

The object of this experiment was to compare the relative efficiency of different phosphatic fertilisers in local soils. Samples of soils treated with equivalent quantities of various phosphatic fertilisers were placed over acid washed sand in suitable receptacles. Paddy was sown and a nutrient solution containing 200 p.p.m. of N and of K_2O was added weekly. The plants were harvested about 10 weeks after sowing. The P_2O_5 content of both leaves and roots was determined. Two soil types were used as in the previous experiment and the tests were carried out in duplicate. The phosphatic manures applied were:—Superphosphate (39%), Basic Slag, Christmas Island Rock Phosphate, Safaga phosphate, Gafsa phosphate and Bone Meal. Quantities applied were equivalent to an application of approximately 10 cwts. Superphosphate per acre. i.e. 22.5 mgms P_2O_5 per 100 grams soil. Results are shown in Table XVI.

TABLE XVI

Uptake of phosphate by plants from soils treated with various phosphatic fertilisers

Treatment	Soil M			Soil R		
	Dry wt. (grams)	Ash (mgms)	P_2O_5 (mgms)	Dry wt. (grams)	Ash (mgms)	P_2O_5 (mgms)
Superphosphate ..	0.87	100.5	8.3	0.82	102.1	10.4
Basic Slag ..	0.83	117.7	7.5	0.78	124.7	10.5
C.I. Rock Phosphate	0.88	105.2	7.7	0.77	87.3	7.4
Safaga Rock Phosphate	0.82	97.0	7.1	0.79	113.4	9.2
Gafsa Rock Phosphate	0.76	100.9	8.0	0.77	99.9	10.1
Bone Meal ..	0.76	99 2	8.0	0.73	98.4	9.7
Control ..	0.72	72.8	6.2	0.68	82.8	6.3
S. E. ±	0.049	3.53	0.309	0.049	3.53	0.309

Considering in the first place the total dry weight of plants, it is calculated that phosphate has produced, on the average of all qualities, a significant increase in yield of 92.5 ± 37.6 milligrams per pot, which is equivalent to 13% of the yield in the control pot. There is a suggestion ($.2>P>.1$) that the Effingham soil has produced larger crops than the Sungei Buloh soil by 40 ± 26.3 milligrams which is equal to 5% of the mean. Differences between qualities are not significant so it is not proven that the soluble fertilisers are superior to the insoluble forms. There is no detectable interaction between soil type and yield response to phosphate.

Considering the uptake of phosphate by the plants, it is revealed that soil type, phosphate and qualities of phosphate have all produced highly significant differences in the amounts of phosphates in the plants; furthermore there is a highly significant interaction of soil type with effects of the various phosphatic fertilisers. When unmanured, approximately equal amounts of P_2O_5 have been absorbed from each soil. In the Effingham soil (M) application of phosphate has increased the P_2O_5 content of the plants, on the average, by 1.56 milligrams per pot, and differences due to qualities are not large. In the Sungei Buloh soil (R) the mean increase of P_2O_5 is 3.30 milligrams, more than twice the increase in the Effingham soil. The greater availability of the added phosphate in the Sungei Buloh soil as compared with soil M is again demonstrated.

The chief contribution to interaction of qualities x soil is that in the Sungei Buloh soil the response to Christmas Island Rock Phosphate has not been greater than in Effingham soil, and the difference in response in these two soils has been greater with Basic Slag than with any of the other phosphate compounds. About 3 milligrams more P_2O_5 was absorbed from Basic Slag in the Sungei Buloh soil than in the Effingham soil, compared with about 2 milligrams more for other qualities except Christmas Island Rock Phosphate.

Phosphate has increased the amount of ash in the plants to a varying degree according to the quality applied, and there is highly significant interaction between soil type and the amount of ash produced with different qualities of phosphate.

There is no detectable correlation of ash or phosphate with dry weight within treatments; neither is there any simple correlation between the P_2O_5 content and dry weight between treatments, such correlation as exists fails to reach statistical significance.

It appears that the availability of different phosphatic fertilisers when applied to local soils is dependent on soil type and to a much less extent on quality of phosphate. The differences in effects due to the different qualities however is not large and there appears to be little of no justification for selecting the more expensive soluble fertilisers in preference to insoluble compounds for application to Malayan soils.

Practical Aspects

In the foregoing account of the phosphate relationships of Malayan soils, certain facts stand out which are of great practical importance. In the first place, the extremely low availability of the native phosphorus in all local soils, a characteristic which is generally well known, would lead one to expect marked responses to treatment with phosphatic fertilisers; yet the effect of such treatment is often small and sometimes undetectable. Results of experiments carried out in this laboratory have shown that local soils have a high capacity for retaining phosphate and there is, therefore, no risk of loss of this nutrient in drainage waters. Large quantities can be applied without any risk of loss provided the phosphate is well incorporated with the soil. The main factors which militate against the economic and efficient utilization of phosphatic fertilisers by plants are (1) the high fixation of the phosphate in a form which is unavailable to plants, and (2) the inefficient distribution of the phosphate in the root zone within the soil mass, owing to its retention by the soil near the point of application. We have seen that even when plants are grown in pots, under conditions which are obviously more favourable for the maximum utilization of the fertiliser than those which hold in the field, usually less than 20 per cent. of the phosphate applied is taken up by the plant. Under field conditions, the percentage utilization must be considerably less. This should be borne in mind when considering the rate of application of fertilisers in the field.

Let us now consider the normal practice followed when fertilisers are applied on Malayan rubber plantations. The quantities of phosphatic fertilisers applied seldom exceed 3 cwts. per acre and the general tendency is towards less liberal rates of application. The fertiliser is usually broadcast on the surface. The surface soil is usually hard and compact, especially in areas of mature rubber where the cover crop is often sparse. Conditions are decidedly unfavourable for efficient penetration of the phosphate and we may assume that the major portion of this plant nutrient is held by the soil

particles at or near the surface. Under the conditions of heavy rainfall which prevail in this country, the soil is always subject to erosion; with every heavy shower a certain amount of the surface soil is lost, the extent of the loss depending on soil type and on the presence or absence of cover crop amongst other factors. The finer soil particles which are lost by erosion contain the phosphate which has been applied. Bearing in mind the loss of fertiliser due to erosion, the high degree of fixation and the negligible vertical penetration of phosphate in local soils, it is evident that the proportion of added phosphate that is ultimately available to the plant is exceedingly small. It is no wonder therefore that response to treatment with phosphate is often disappointing. These facts lead to considerations of how the application of phosphatic fertilisers can be conditioned to favour a more efficient absorption by the plant.

The first and most obvious consideration is whether greater and more economic responses to treatment with phosphate can be obtained by increasing the rate of application. The results of the present investigation has led the writer to the conclusion that the amount of fertiliser generally applied in areas of mature rubber trees is low in comparison with the amounts considered necessary for some of the soil types of Malaya. That the practice of applying a standard dressing to all soils is unsound has been demonstrated; it does not necessarily follow that two soils which are equally deficient in phosphate will show the same response to treatment with a given limited quantity of fertiliser. It must be realised that the ordinary field dressings of a few hundredweights at most may be fixed immediately in a form which is difficultly available, and in some soils such limited amounts will be almost completely unavailable. The possibility of saturating the soil with phosphate might be suggested, so that all phosphate added subsequently will be available to the plant. The fixation capacity of local soils however is so immense that the amount of phosphate required to saturate the soil is beyond the limits of practicability. Other means of combating fixation and increasing the efficiency of fertilization must therefore be considered.

The first essential is to maintain favourable soil conditions. As stated above, most Malayan soils have a tendency to form a hard crust on the surface when exposed to the sun. Vertical penetration of applied phosphate under such conditions will be negligible and there is always a risk of considerable loss of fertilisers either by direct wash or by

erosion of the finer soil particles on the surface. The most effective way of improving the structure of the surface soil, thus facilitating the penetration of fertilisers, is to maintain a dense but well controlled cover crop. The need for maintaining a cover has already been emphasised in numerous publications and the reasons for this emphasis are generally well appreciated locally, but perhaps it is not fully realised how severe may be the loss of applied fertilisers, especially phosphates in the absence of a cover.

More rational methods of application must be considered to ensure the most efficient utilization of fertilisers. This is essential, not only to assure economic returns in the form of increased yields but also to conserve our potential supply of phosphate. Broadcast application of the powdered fertiliser on the surface of the soil, as generally practised in this country, is probably the least satisfactory method under local conditions. Soils do not easily permit penetration, and fixation occurs most readily when finely ground fertilisers are used because of the greater surface exposed to the soil. The rate of fixation can be reduced by applying phosphate in the form of granules or pellets because there is less surface exposed to the soil. A greater proportion of the phosphate applied in this form will be readily available to plants because the soil in the immediate vicinity of the granules becomes fairly saturated with phosphate, much of which is in excess of the amount fixed in that limited volume of soil. Furthermore, the phosphate will be available over a longer period because large particles dissolve more slowly than small ones.

Granular fertilisers have no advantage unless they are incorporated with the soil. Results of experiments discussed in this paper have shown that the downward movement of phosphate is restricted no matter whether the fertiliser particles are coarse of fine. Some method other than surface application must therefore be considered to ensure the most efficient utilization of the fertiliser.

The most effective way of treating the highly acid, phosphate fixing soils of Malaya is by the so called placement methods. The fertilisers should be placed below the surface of the soil to prevent any risk of loss by wash, and at the same time they should be placed in such a manner that they provide high concentrations of available phosphate in the absorbing radius of plant roots. Two methods may be considered both of which are applicable to tree crops. In the first method limited quantities of phosphate manure is placed at the bottom of a furrow between tree rows, which afterwards

should be filled with soil. Both soluble and insoluble fertilisers may be applied by this method but there is no conclusive evidence to show that the more expensive soluble fertilisers are more beneficial than the insoluble forms in local soils. The powder form of fertiliser may be used, but as stated above, the best form is some granulated product if available. Relatively coarse grained material should be selected if the granulated form is not available. Small fertilizer briquettes have been used with success in other countries, but these are not yet manufactured on a commercial scale. They would be eminently suitable if they could be produced at a reasonable cost since they slowly disintegrate by the action of the roots which grow closely around and within the briquettes without becoming mixed with the soil. The loss of phosphate due to fixation is therefore reduced to a minimum.

The second method which may be considered is the application of the fertiliser in a series of holes dug around the tree with a changkol, a crowbar or an auger. This is simple and relatively inexpensive.

There is still a great deal to be learnt about the effect of phosphate on rubber trees but there is ample evidence to show that applications of adequate supplies of phosphate to most Malayan soils can be expected to increase appreciably their rate of growth, especially in the early stages. It is imperative therefore that improved methods of application of the fertiliser should be adopted whereby the maximum amount can be made available to the plants. Factors which have been considered in the foregoing pages confirm the necessity for liberal and judicious application of phosphate.

Regarding the type of phosphate most suitable under local conditions, the evidence accumulated so far indicates that insoluble forms of phosphate such as Christmas Island Rock Phosphate, are just as effective as the more expensive soluble fertilisers in most local soils. Whether this applies to all Malayan soils is not certain and this aspect of the problem will be investigated further.

Summary

1. The penetration of phosphates in Malayan soils has been studied and the results show that all soils greatly impede the downward movement of phosphate.

2. Soils vary in the extent to which they permit the penetration of phosphate. In some of the high fixing soils as much as 75% of the amount added may be held within

half an inch of the surface and about 90% within the top inch. Nearly all the phosphate was retained in all soils within three inches of the point of application. These tests were carried out in the laboratory and it may be expected that the degree of penetration of phosphate under field conditions will be much less.

3. The phosphate of sodium penetrates more deeply than other soluble forms of phosphate tested. Superphosphate exhibits the least efficient power of penetration.

4. The degree of penetration of superphosphate is independent of the size of particles applied but the availability of the phosphate retained appears to be greater when the coarser particles are used.

5. Only a small proportion of phosphate applied to local soils is utilised by plants. The uptake of phosphate was considerably reduced when the readily soluble fraction was removed by extraction with dilute sulphuric acid. The agreement between the amount of readily soluble phosphate (i.e. the so-called " available " phosphate as determined by a conventional chemical method), and the amount absorbed by the plant is discussed.

6. Response to treatment with different phosphatic fertilisers varies according to soil type. The uptake of phosphate by plants is greater in some soils than others. Differences between qualities of phosphate are small and there is no convincing evidence that soluble phosphatic fertilisers are more effective than the insoluble forms in Malayan soils.

7. The practical aspects of phosphate manuring are discussed and improved methods of application of fertilisers are suggested.

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